ARMORED MEDICAL RESEARCH LABORATORY
Fort Knox, Kentucky

Project No. 26
741-2 SPMEA

5 August 1944

1. PROJECT: No. 26 - Investigation of Ear Plugs for Protection against Gun Blast. (Subject Items: NDRC-Ear Wardens, M. S. A. Ear Defenders, Sepco Ear Protectors, Cotton, Rubber Plugs with Baffles and NODS.

a. Authority - 4th Ind. HQ. AGF, 426 (18 Oct 43) (R) GNRQT 6/62327, 3 Dec 1943.

b. Purpose -

(1) To investigate the extent of need for acoustic protection.

(2) To determine the degree of protection contributed by certain devices.

2. DISCUSSION:

a. Military personnel are exposed to many sources of noise and blast and it is common knowledge that some exposures, such as to artillery fire are associated with a significant rate of hearing loss which becomes evident after years of exposure.

b. One consequence of this is that men who are increasing in value because of years of experience are being made progressively less efficient because of increasing deafness. Moreover, deafening of men may be followed by a post-war disability compensation problem with all that it entails. In addition to the permanent loss which follows longtime exposure, there is a temporary, partial, deafness brought on by noise which may be painful, is distracting, and interferes with the effective understanding of orders and communications.

c. In general, therefore, the argument for protection of hearing is sufficiently strong to warrant acceptance of the principle. One needs, however, to establish where the requirement for such protection exists and to demonstrate that protective devices are of practical use. It has previously been established that the noise level in tanks does not cause hearing loss in men doing intensive driving (A.F.M.R.L. Report on Project 5-8, 20 January 43). Accordingly the current investigation was limited to study of the acoustic effects of blast and noise from gunnery. For this, a series of 45 gunnery instructors, taken at random from a group with varying durations of exposure, were examined. In determining the relative degree of protection contributed by various test plugs, a group of 14 men with minimal previous exposure to high noise levels or gun blast were used. Details of procedure and the results are given in the Appendix.

3. CONCLUSIONS:

a. Acoustic protection is needed for all personnel who are regularly exposed to the noise of gun fire or to blast.

b. The characteristics and course of the temporary loss are like that following exposure to sustained high noise levels.

c. Expedients in current use (cotton and waste) are insanitary and not entirely reliable.

d. Of the plugs tested, NODS, and the baffled rubber stopper were inadequate and impractical to use.

e. M.S.A. Ear Defenders, N.D.R.C. Ear Wardens and Sepco Plugs provide the best protection against temporary loss. Sepco plugs are somewhat less satisfactory because of higher attenuation of speech.

4. RECOMMENDATIONS:

a. That acoustic protective devices be provided for gun crews, gunnery instructors and other regularly exposed to gun fire from large guns or to gun blast.

b. Basis of issue to be 1 pair of plugs per man exposed.

SUBMITTED BY:
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APPROVED Willard Machle
WILLARD MACHLE
Colonel, Medical Corps
Commanding

3 Incls.
Incl. #1 - Appendix
Incl. #2 - Photograph
Incl. #3 - Figs. 2 thru 9

APPENDIX

1. Effects of High Sustained Noise Levels. Continued exposure to high noise levels brings about a deterioration in acuity of hearing not unlike that which often occurs as part of the aging process. The initial loss is of a fatigue type and is temporary in character so that recovery may take place in from 12 to 24 hours. With repeated exposure longer periods of recovery are required; recovery may not be completed before re-exposure, the loss becomes cumulative and permanent loss of hearing may result. The degree of fatigue loss and the onset of permanent loss are both related to the intensity of sound exposure and to its duration. Permanent deafness may result from intermittent exposure at high intensity for from 200 or 300 hours or may come on after 10 or 15 years, in which instance it will perhaps be manifested as a premature aging of the ear.

2. Effects of Blast. Much less is known concerning the effect of exposure to gun blast and noise. Blast waves of high intensity are known to rupture eardrums, even causing displacement, but the long-time effect of less severe exposures has not been clarified.

3. Methods of Acoustic Protection. All methods of protection now in use depend upon exclusion of the energy of the sound or blast wave from the eardrum or attenuation in passing through the protective device. The simplest, the stopping of the canal with the fingers, is one of the most effective. Headsets, helmet flaps, etc. confer a high degree of protection. Most commercial ear defenders are designed to be inserted into the ear canal and to be worn throughout the period of potential exposure; such use, consequently gives rise to certain considerations which may greatly effect the usefulness of the device.

4. Considerations in the Selection of Ear Plugs. The degree of acoustic protection should be such that the wearer experiences no unpleasant sensations or noticeable hearing losses after exposure. The attenuation at different frequencies should be roughly constant so as to prevent undue distortion of articulation. A high degree of attenuation of sound is undesirable because it would raise the speech threshold level to the extent of interference with normal communication. To facilitate general issue, plugs should be of such a design that only a few sizes are necessary to fit all ears. They should provide the required seal without the use of oils or jellies, since such materials complicate supply. Viscocity changes in oils under varied temperature conditions also introduce a problem. The effect of the shape and material of construction of the defender on the sensitive ear canal must be considered since comfort is as important as good acoustic insulation. The plug material should not be deteriorated by the action of ear wax. Other practical considerations include the ease of insertion and removal, cleanliness, and durability of the plug.

5. Procedure. Test procedure for this project was divided into two distinct parts: the establishment of a requirement for the need of ear protection, and tests to determine which of the subject plugs provide the best protection. The group of tests conducted in the establishment of the

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requirement were conducted in two phases: observations on the effect of gun blast on unprotected ears, and audiometric measurements on a large group of gunnery instructors who had been exposed to gun-fire blast for periods of one to twenty-four months. Tests to determine the best of submitted ear protectors consisted of a systematic series of controlled experiments on personnel wearing subject protective devices.

a. To obtain basic data on the effect of gun blast on personnel who have been subjected to considerable exposure, 45 men were selected at random from a group of gunnery instructors. Most of these men had been subjected to blast exposure for six to eight hours daily for six consecutive days after which they were away from the exposure area for one or more weeks before returning for another week of exposure. The men were tested a minimum of two hours after their last proximity to a firing area, and most of them had not had fire exposure for a week or more. Audiograms were determined and the percent of deafness per man calculated, based on the method tentatively accepted by the American Medical Association.

b. To investigate the controlled effect of gun blast on the unprotected ear, two men were used as test subjects. Each day, with test ear exposed they were subjected to blast of one round from a 75 mm gun, with the unprotected ear always at a distance of eight feet norman to the tube of the gun. Audiometric measurements were recorded within three minutes after exposure and repeated at intervals of two, four, and twenty-four hours. The twenty-four hour audiogram was then used as the base line for the following exposure. This procedure was continued for eight days after which time daily audiograms were obtained to determine the rapidity at which the ear returned to its normal base line without additional exposure to blast. One trial was made to determine the effect of 37 mm and 30 cal machine gun blast on an unprotected ear in a controlled test. Three men whose normal base line audiograms were known were exposed to the blast from one round of the 37 mm gun at a distance of eight feet normal to the muzzle and an after exposure audiogram made for comparison with the trend in hearing loss resulting from exposure to the 75 mm gun. Similarly, audiograms were made on three subjects after 25 rounds of 30 cal machine gun, respectively, each at a distance of six feet normal to the machine gun.

c. Tests for the selection of the most adequate of submitted ear plugs were divided into two general groups, preliminary and final. The preliminary group consisted of obtaining basic data in order to conduct a comprehensive study of selection of protective devices.

(1) Preliminary - A purposive selection of fourteen men between the ages of eighteen and twenty years, based upon otoscopic and audiometric examinations from a group of twenty-five men were made. This unit had not had any recent exposure to gun fire or other loud noises. Two of these men were used for the controlled test on exposure with unprotected ears noted earlier. Audiometric examinations were made within an insulated ambulance, approximately 1000 yards from the blast source. Before exposure these subjects were tested several times over a period of four days and a pre-exposure audiogram established as a base line. The tests were repeated

until the results checked within the margin of error. The better ear was then designated as the test ear, and the other served as a control. In order to protect the control ear from blast and noise which might alter its control characteristics, it was sealed with a soft rubber plug inserted in the ear canal, covered by a soft sponge rubber pad which covered the external ear. This was held in place under a heavy cloth helmet by a broad rubber band. Following an exposure, the subject was transported quickly from the exposure area to the examination location, arriving for examination within three minutes following the last round of exposure to gun fire. The apparatus used for measurement was a standard Maico Audiometer with ten pure tone frequencies, 128, 256, 1024, 2048, 2896, 4096, 5792, 8192 and 11584 cycles per second, calibrated previously against pure tones of each frequency. The hearing loss range was from a minus ten to one hundred decibel calibration.

To obtain data on the general behavior of plugs, the following six protectors, (See Fig. 1), cotton, oiled cotton, MODS, Sepco, N.D.R.C. and M.S.A were tested on two subjects each. With the plug in the test ear, the subjects were exposed to 75 mm gun blast for periods of from 2 to 4 hours. The exposure area consisted of a circle, 6 feet in diameter, the center of which was nine feet from the muzzle and approximately 45° off axis to the rear of one gun, and at a distance of approximately thirty feet normal to the muzzle of a second gun. An audiogram was done immediately after exposure, the difference between the normal base line audiogram and the audiogram obtained following exposure was used as a measure of hearing loss. This procedure was repeated for five trials during which time the degree of blast exposure per subject varied from a minimum of 36 rounds to a maximum of 222 rounds for any single trial day.

(2) Final - A comprehensive study of three test plugs, NDRC, MSA and SEPCO, was made following the preliminary investigation. The determining tests for the adequacy of plugs were conducted with three groups of four men, each group wearing one of the above protectors. The plugs were rotated among the groups daily for three trials so that each group wore each plug for one exposure period. In doing this the element of individual sensitivity was eliminated since the sensitive individual would react equally in this respect to all plugs. Each subject was then exposed to four consecutive rounds of gun blast from a 75 mm gun at a distance of six feet normal to the muzzle. As in preceding tests an audiogram was made immediately following this exposure, and these were averaged for each plug, the average representing the hearing loss suffered with any one of the plugs based on twelve subjects tested under identical exposure conditions. An additional single trial test was conducted on the Schein Plug by comparison with an NDRC plug, the results of the latter known for the subject individual. Test exposure period and distance for this test was the same as above tests.

(3) Preliminary blast pressure and sound intensity measurements were made to determine the extent of pressure and intensity sustained by the test subjects during exposure. Noise intensity was in excess of 140db and pressure measurements varied from 0.60 to 1.30 lbs. per square inch.

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6. Results.

a. Evidence of deafness found in the test of the 45 gunnery instructors is an indication of the chronic accumulation of auditory injury. The average incidence of useful hearing loss of the group, 10.24%, determined by the A.M.A. method of calculation (See Fig. 2), is not great, but significant losses are indicated in the higher frequencies. This is illustrated in Fig. 3 for four frequencies, 256, 2048, 2896 and 4096 cps. The histograms reveal that approximately 80% of the group had losses of 20 db. or less at 256 cps., yet 49% had a loss in excess of 60 db at 4096 cps. which is within the range of frequency first to be effected by blast and noise exposure. The graph also indicates that slightly over 35% of the group suffered a hearing loss of 40 db. or greater at 2048 cps., which is within the center speech range.

b. The controlled effect of gun blast on unprotected ears is one of definite accumulation of temporary hearing loss. This is illustrated in Figs. 4a and 4b for two individual test subjects, each of whom had received a daily exposure of blast from a single round of a 75 mm gun at a distance of 8 feet normal to the muzzle. Curves illustrate the change in the individual normal base line (the audiogram before exposure daily) and the daily peak audiogram, which was made immediately following exposure daily.

Somewhat similar hearing losses result from exposure to blast from other weapons as shown on Figures 5a and 5b. These audiograms were obtained following exposure to the 37 mm gun and the 30 cal machine gun. Peak temporary losses occur at the same frequency as with the 75 mm blast.

Recovery of hearing is indicated for two test subjects in Figure 6. The curves show a trend toward normal after removal from blast exposure.

Preliminary selection from the six types of ear protectors was based upon a 5-trial period with varying degrees of exposure. Resulting audiograms, showing average change in hearing loss for the five exposure periods, are shown on Figure 7. Comparisons were not clear cut, indicating the need for better control of exposure and elimination of individual variability by rotation of subjects and plugs. Because of reasons of supply, attenuation, cleanliness and sturdiness to wear, NODS, Oil Cotton and Cotton were eliminated from the final test group, leaving N.D.R.C. Ear Wardens, MSA Ear Defenders, and Sepco Plugs. Figure 8a shows the average audiograms for 12 test subjects, wearing these plugs in rotation and all receiving identical exposure. The curves are compared with the audiogram for an unprotected test subject following a one round exposure. Result for the 3 plugs are clear cut with evidence of only minor differences between the three defenders. All test subjects were questioned regarding comfort in wearing test plugs particularly during the blast period. All reported that the three plugs were equally comfortable, and that they experienced no pain from the blast of the gun. Attenuation tests were made to determine the degree of insulation provided by the 3 ear protectors against tones in the center speech range, but also including the overall 10 pure tones from 128 to 11584 cps.

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The results, illustrated in Figure 8b, show the MSA and NDRC protectors to have a less attenuation value than the Sepco plug, thus permitting more acute hearing of commands with plugs inserted.

As only a single Schein plug was submitted for test it was compared to the NDRC device, using for the test a subject, who had an excellent score with the latter protector. The test procedure and degree of exposure were the same as in the previous tests. The results shown in Figure 9, indicate that the Schein plug provides inadequate protection.

APPENDIX

N.D.R.C.

M.S.A.

NODS

SEPCO

SCHEIN

FIG. 1
ILLUSTRATION OF TEST PLUGS
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FORT KNOX, KY.

Project No. 26

N.D.R.C.

M.S.A.

NODS

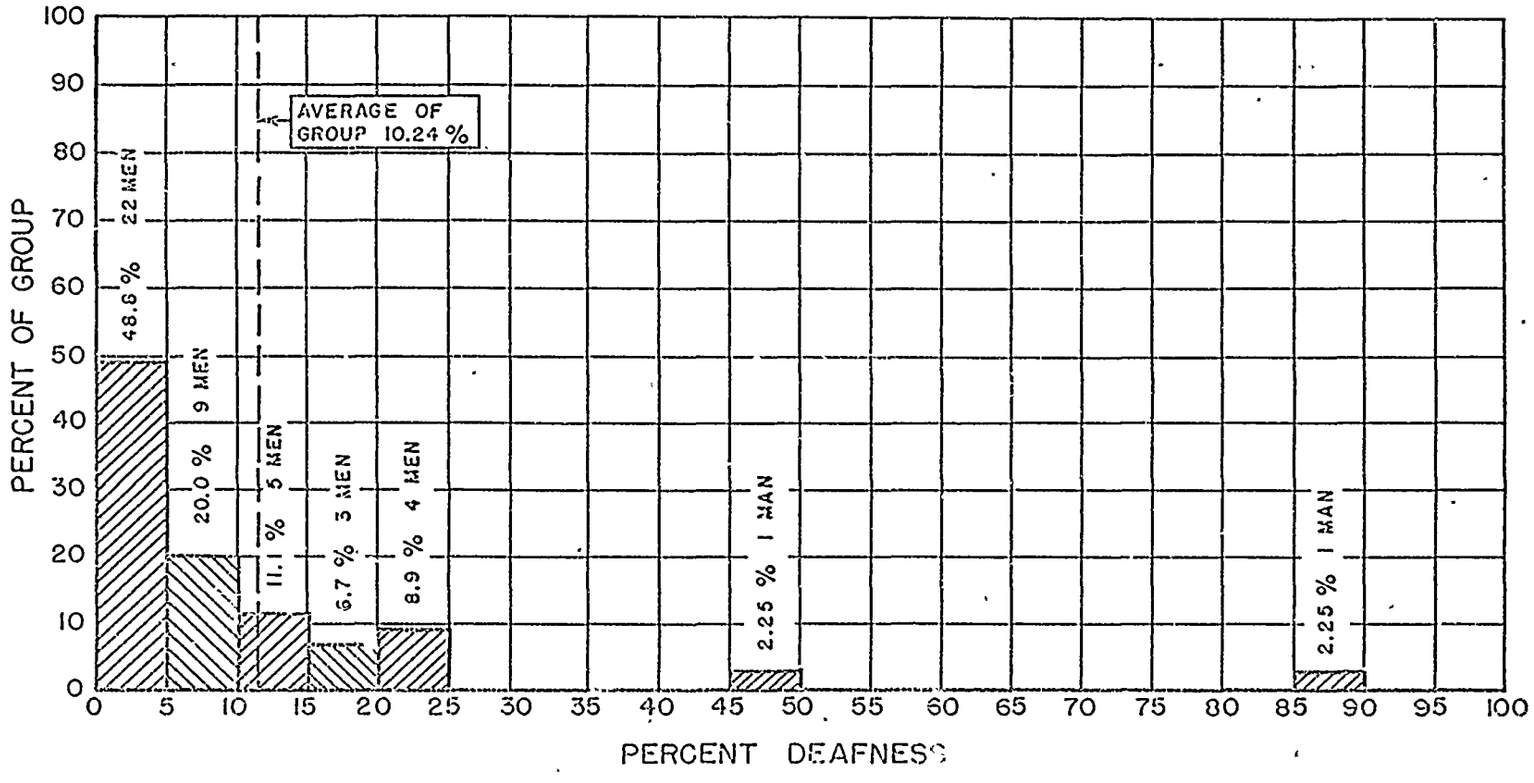
SEPCO

SCHEIN

FIG. 1
ILLUSTRATION OF TEST PLUGS
ARMORED MEDICAL RESEARCH LABORATORY
FORT KNOX, KY.

Project No. 26

LOSS OF USEFUL HEARING * IN PERCENT IN A GROUP OF 45 GUNNERY INSTRUCTORS



* J.A.M.A.

FIG. 2

FIG. 2

DISTRIBUTION OF LOSS OF HEARING
IN 45 GUNNERY INSTRUCTORS

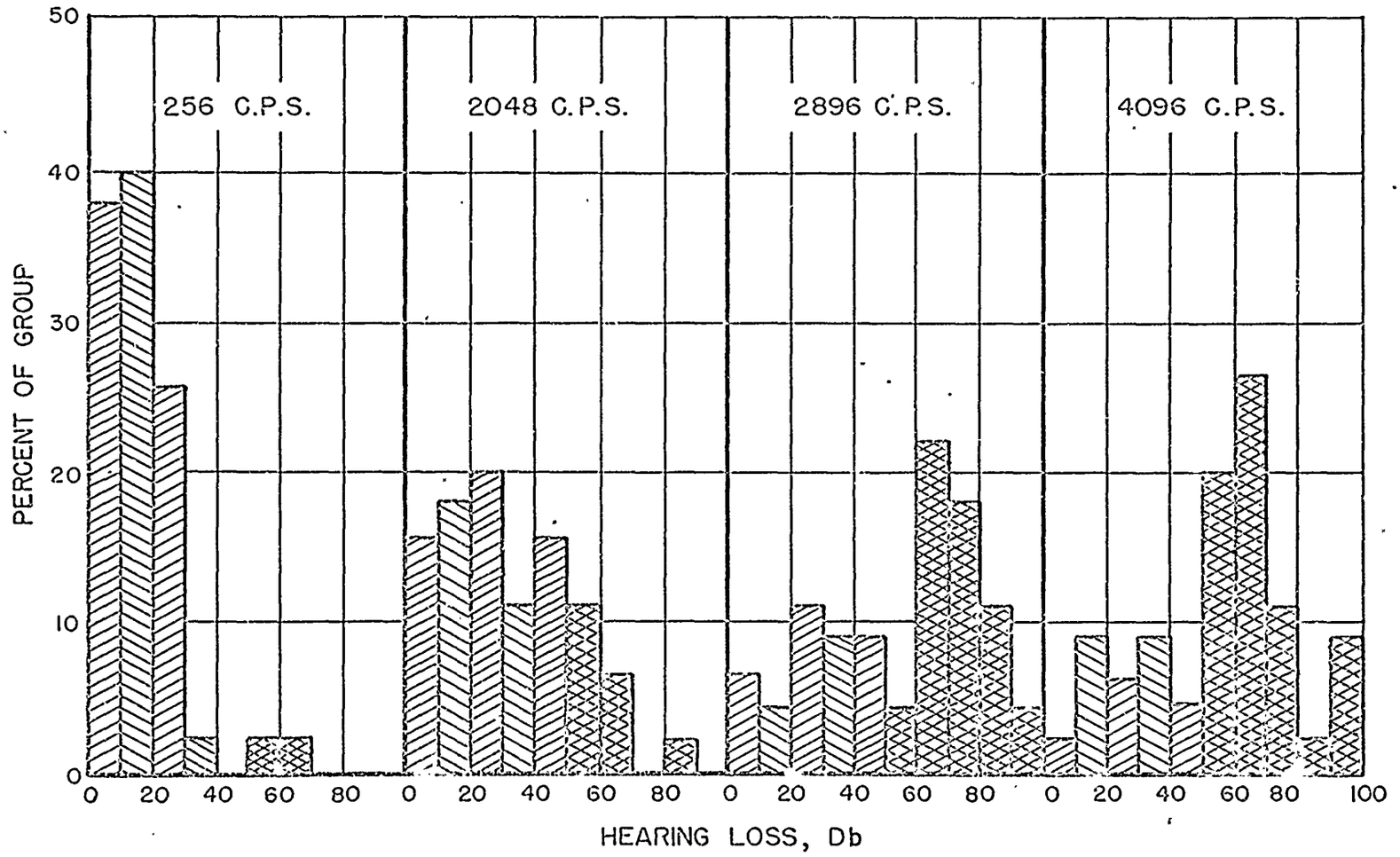


FIG. 3

FIG. 3

FIG. 4a

CUMULATIVE HEARING LOSS FOLLOWING ROUTINE EXPOSURE OF UNPROTECTED EAR - CASE M AUDIOGRAMS PRIOR TO AND IMMEDIATELY FOLLOWING EXPOSURE (1 RD.-75 MM)

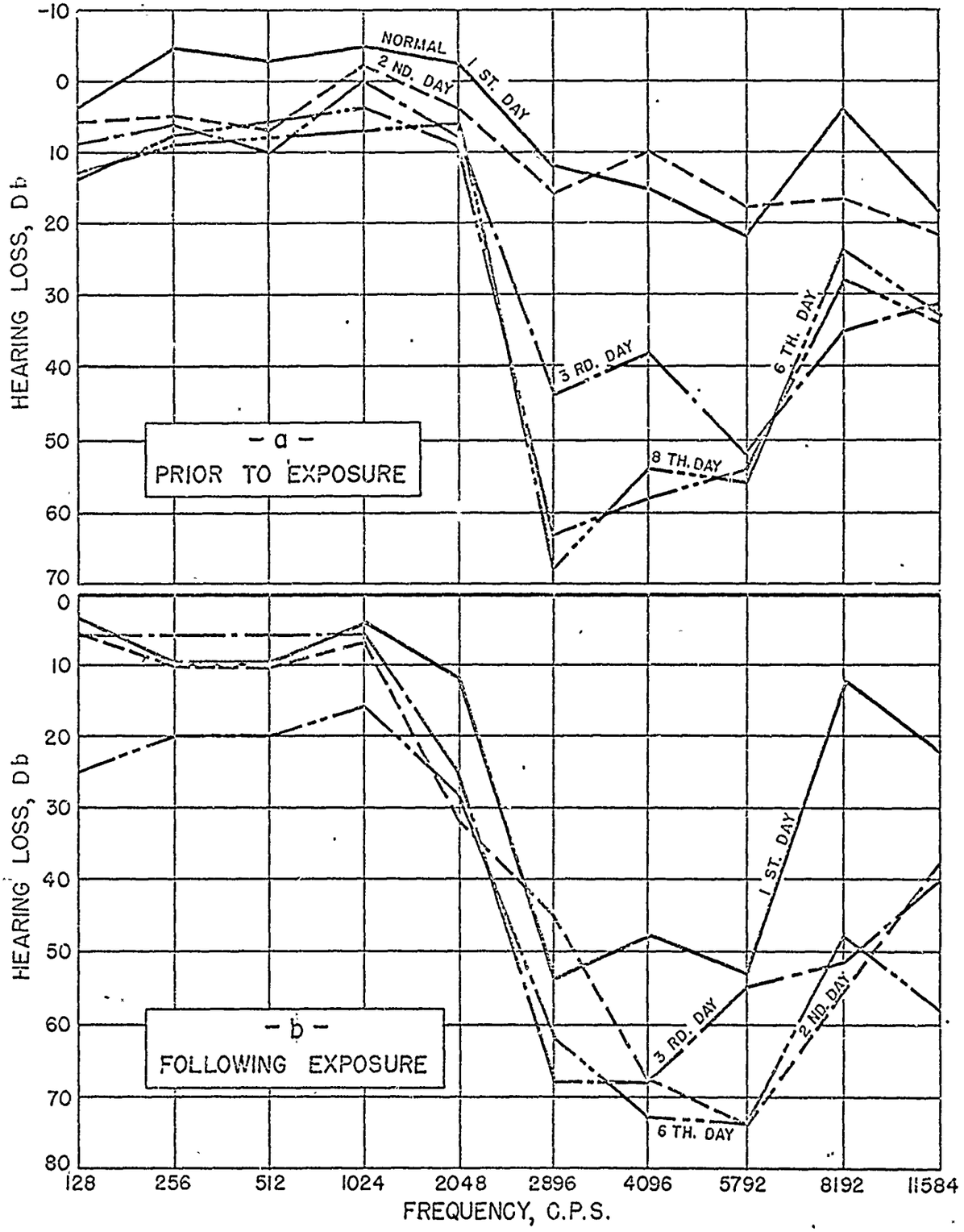


FIG. 4a

FIG. 4 b

CUMULATIVE HEARING LOSS FOLLOWING ROUTINE EXPOSURE OF UNPROTECTED EAR - CASE P AUDIOGRAMS PRIOR TO AND IMMEDIATELY FOLLOWING EXPOSURE (1 RD - 75 MM.

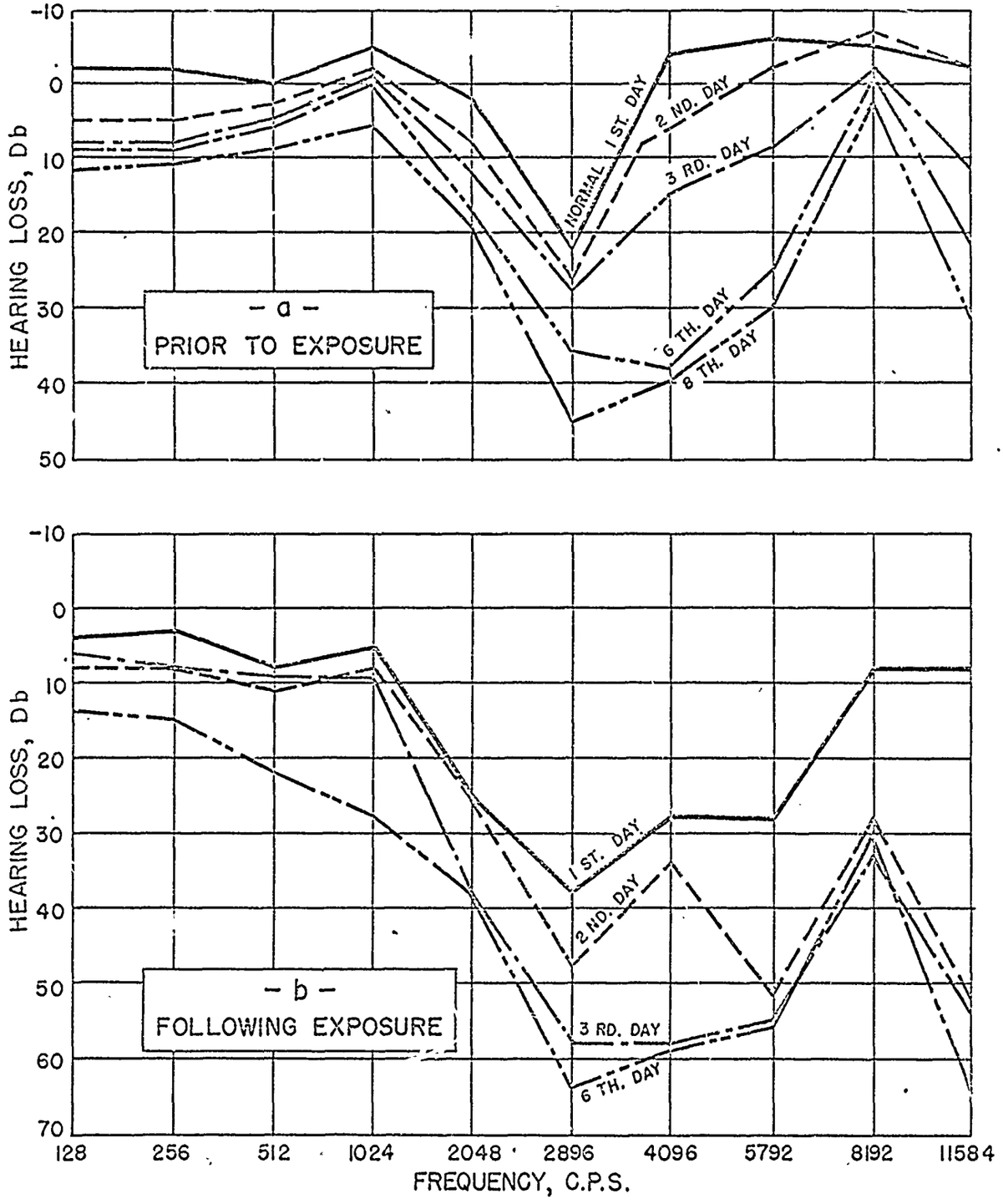


FIG. 4 b

FIG. 5a

TEMPORARY LOSS FROM STANDARDIZED EXPOSURE TO 37 MM AND 30 CAL BLAST

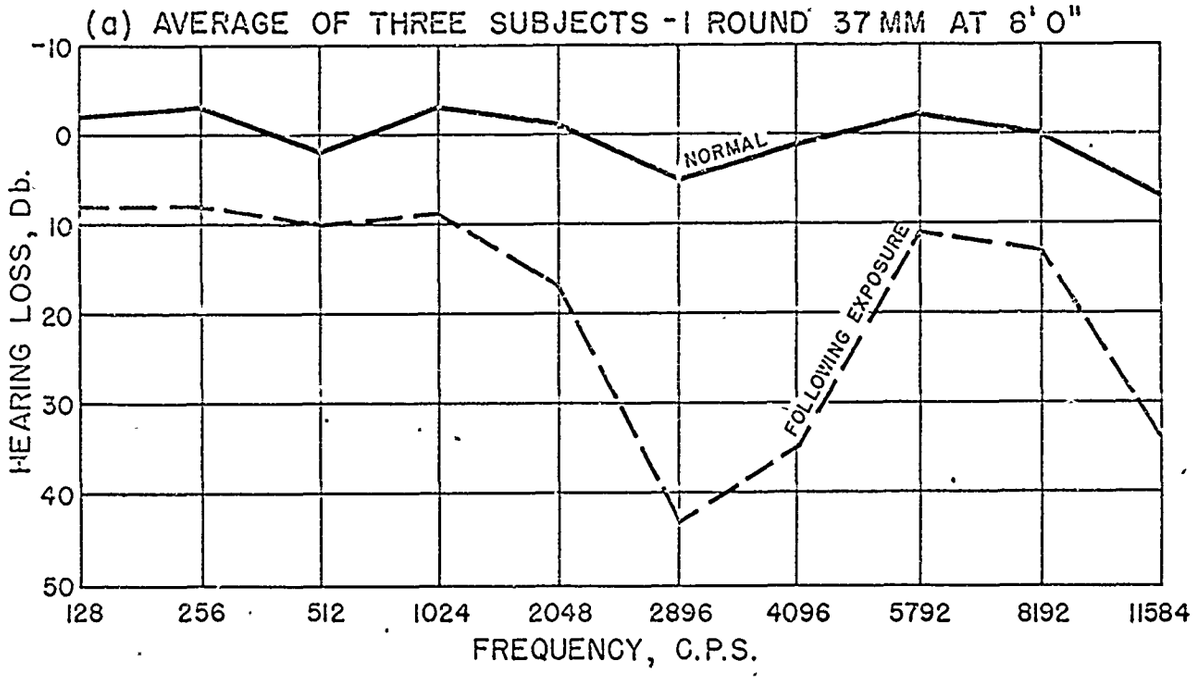


FIG. 5b

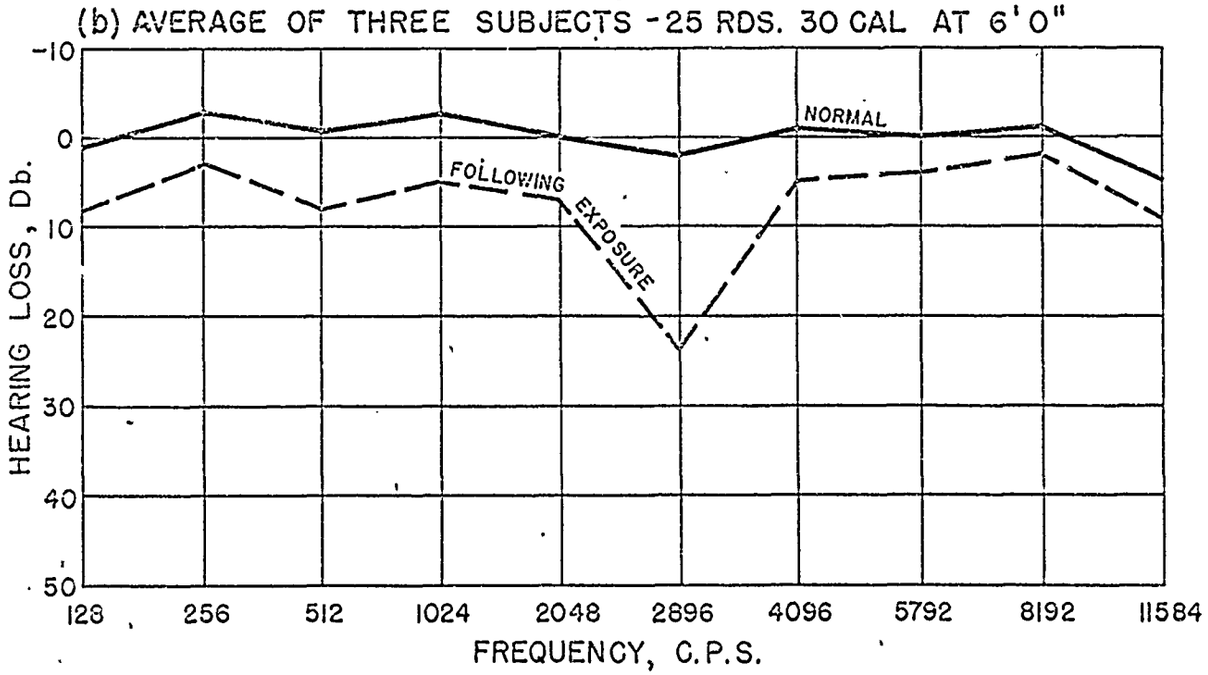


FIG. 5a & 5b

FIG. 6

HEARING LOSS RECOVERY CHART

AUDIOGRAMS FOR DAYS FOLLOWING LAST EXPOSURE TO GUN BLAST

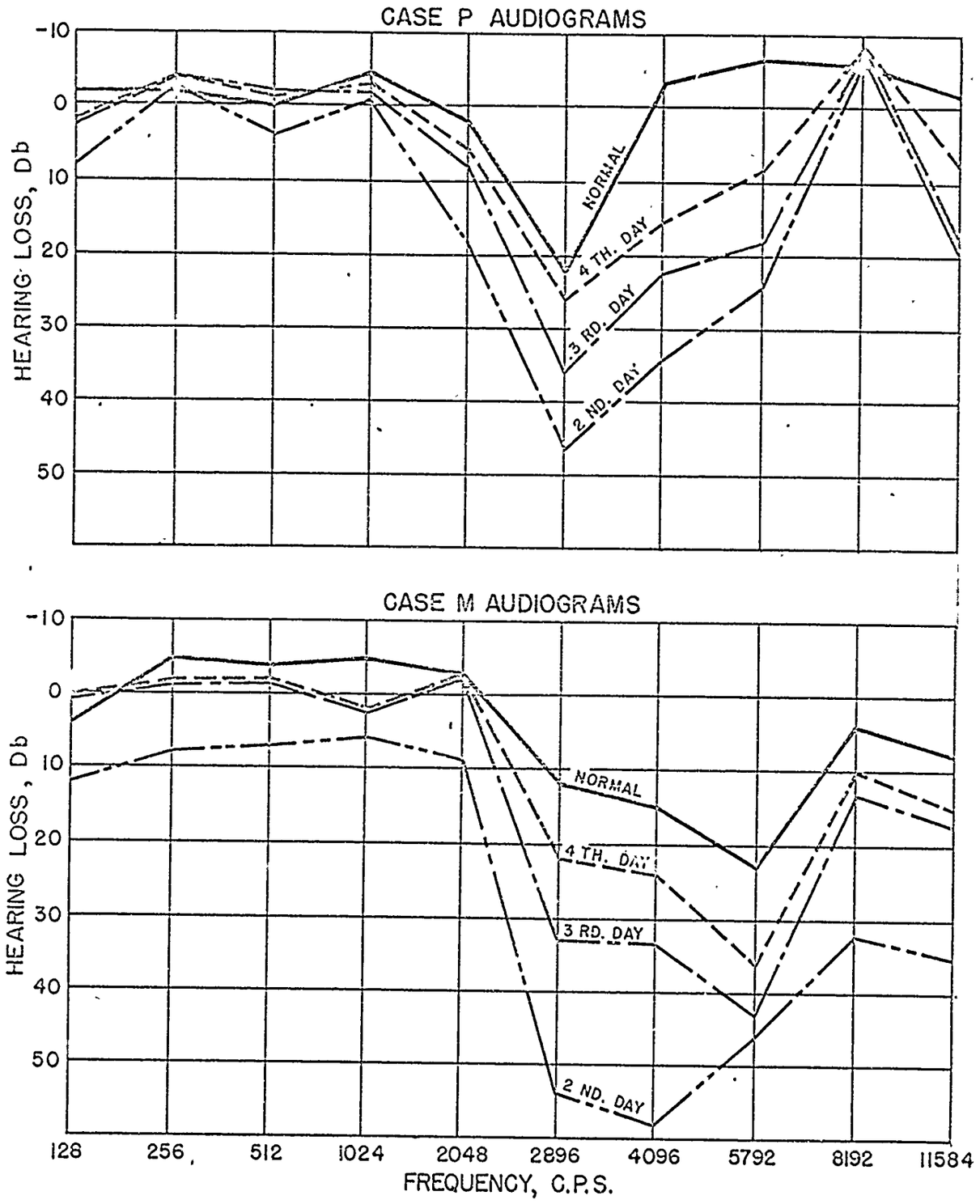


FIG. 6

AVERAGE HEARING LOSS CHANGE FOLLOWING PRELIMINARY EXPOSURE USING SIX PROTECTIVE DEVICES

(2 MEN TESTING EACH PLUG)

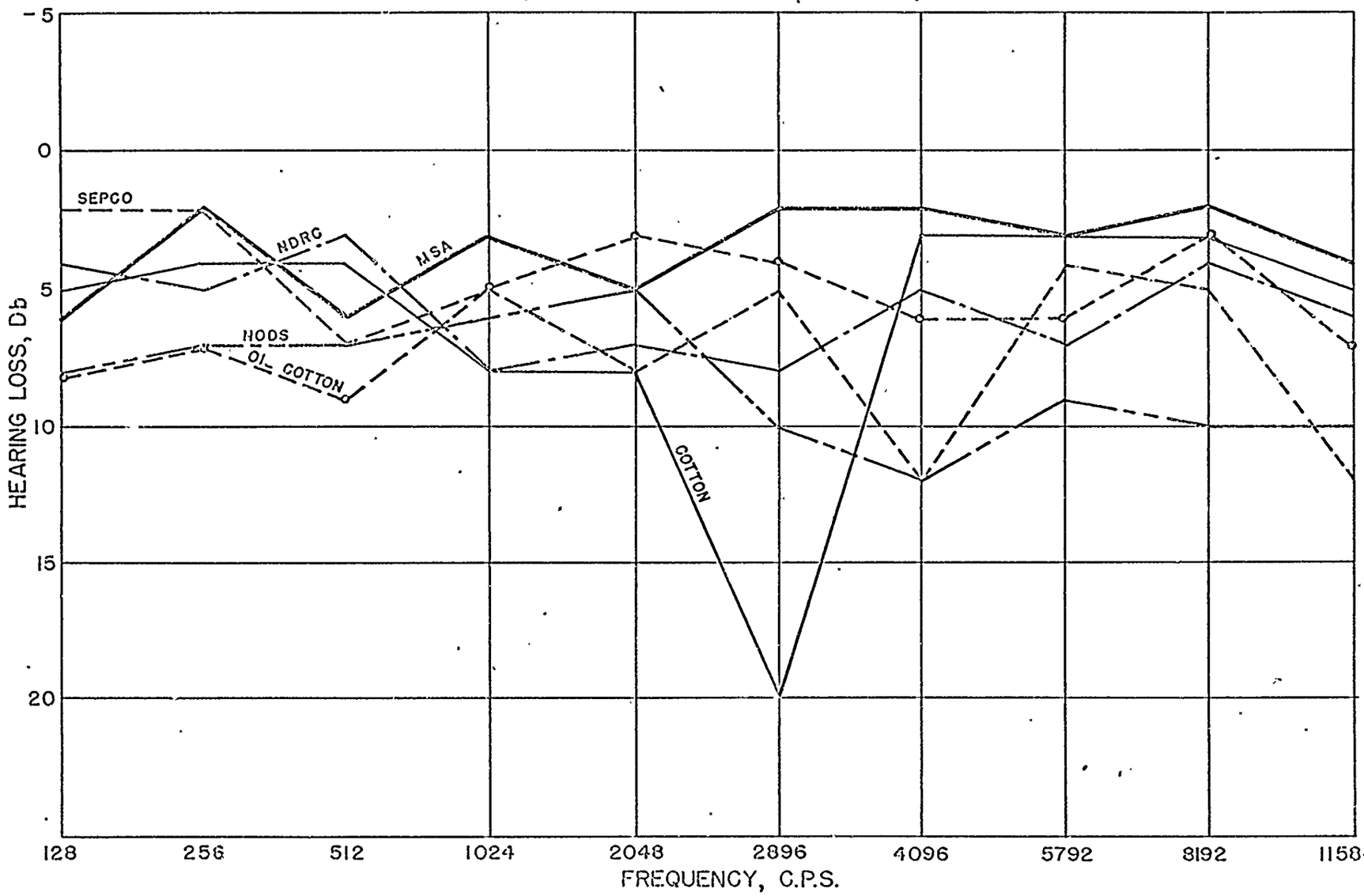


FIG. 7

FIG. 7

FIG. 8a

TEMPORARY LOSS FOLLOWING STANDARDIZED EXPOSURE USING THREE DEVICES

* EACH AUDIOGRAM REPRESENTS AN AVERAGE OF 12 TEST SUBJECTS EACH WEARING 3 TEST DEVICES FOR 3 EXPOSURE PERIODS

** CONTROL

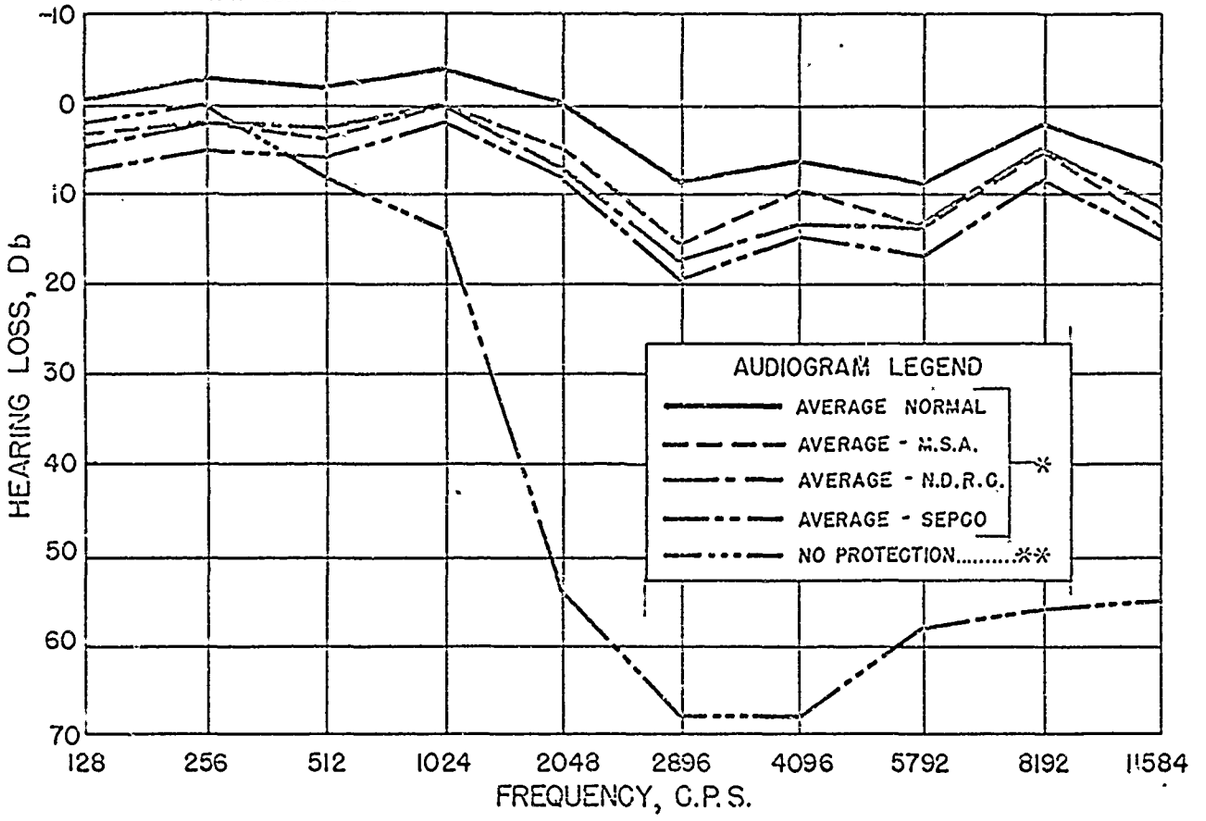


FIG. 8b

AVERAGE ATTENUATION OF TEST EAR DEVICES

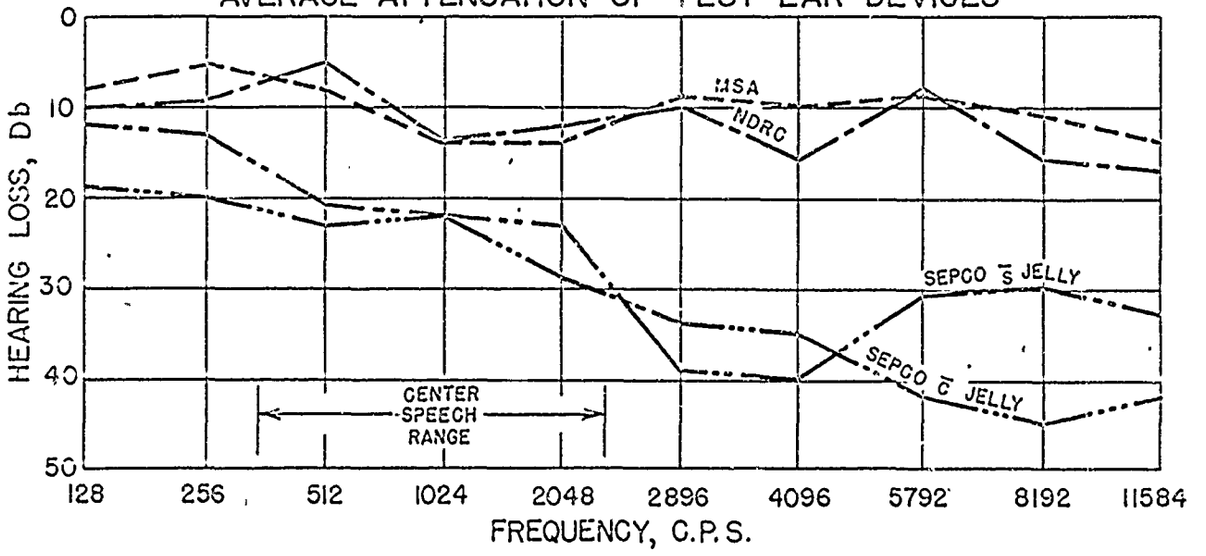


FIG. 8a & 8b

FIG. 9

COMPARISON OF NDRC PLUG WITH SCHEIN PLUG ON SAME TEST SUBJECT FOR IDENTICAL EXPOSURE, TEMPORARY HEARING LOSS

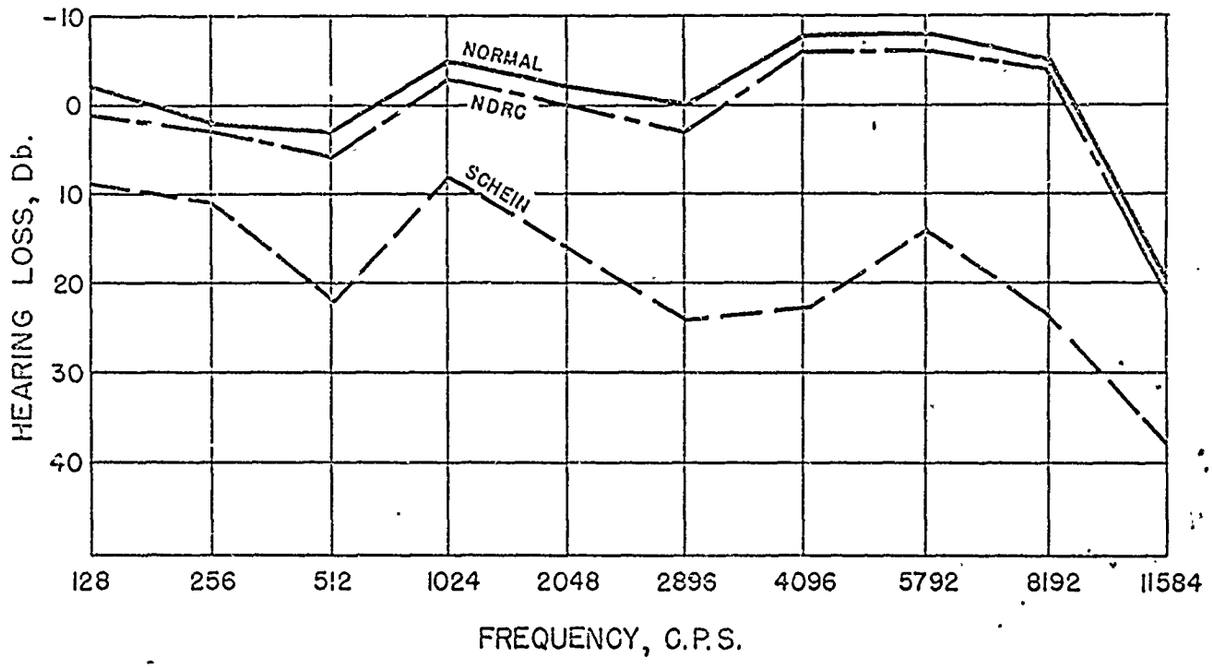


FIG. 9.